"English Translation" #2

Optical arrangement for use in a laser diode arrangement and a laser diode arrangement with one such optical arrangement

The invention relates to an optical arrangement as claimed in the preamble of claim 1 and to a laser diode arrangement as claimed in the preamble of claim 41.

The radiation of a semiconductor diode laser (here, in simplified terms, also a diode laser) is characterized by a highly diverging beam, in contrast to conventional laser beam sources with a laser beam which has a diameter of a few millimeters with low beam divergence in the range of a few mrad, while the divergence for a diode laser exceeds 1000 mrad.

Furthermore, it is also known that in diode lasers the angle of divergence in the plane perpendicular to the active layer, i.e. in the so-called "fast axis", is greater than in the plane of the active layer, i.e. in the so-called "slow axis".

To attain laser power as high as possible, for example 20 - 40 watts from a semiconductor chip, numerous emitters are combined on a so-called bar. Ordinarily 10 - 50 individual emitters or emitter groups are arranged following one another in a row in the plane parallel to the active layer, i.e. in the slow axis. The resulting overall beam of this bar in the plane parallel to the active layer has an opening angle of roughly 10° and a beam diameter of roughly 10 mm. This yields a beam quality in this plane which is many times less than the beam quality in the plane perpendicular to the active layer.

The occupation density which results from the quotient of the radiating area of the laser bar to the total area in currently available diode laser bars is roughly 30 - 50%, in any case higher occupation densities allowing only pulsed operation of the laser. For continuous applications therefore smaller occupation densities are necessary.

In order the make the highly divergent radiation of a diode laser useful for laser applications, for example material machining, medical technology, pumping of solid state lasers, etc., collimating and focussing optical arrangements are necessary in the beam path. These optical arrangements comprise in general especially one fast axis collimator which is made as microoptics and which has the optical property of a cylinder lens which lies with its axis parallel to the slow axis, for all emitters of a diode laser bar its own continuous cylinder lens being used with a small focal distance in the immediate vicinity of the facet of the diode laser bar, i.e. at a distance of a few hundred mμ from the emitters or from this facet. The divergence in the slow axis is then corrected by following macro-optics.

To attain higher powers, as are necessary for example in materials machining, in medical engineering, for pumping of solid state lasers, etc., providing several rows of emitters or several diode laser bars in a stack in several planes on top of one another is known, these planes being offset against one another in the direction of the fast axis and to each row of emitters or each diode laser bar of each plane its own fast axis collimator being assigned.

In particular, a laser diode arrangement (US 5 802 092) is also known in which the slow axis collimator is formed by a host of cylinder lens elements which follow one another in the direction of the slow axis and which with their axes are each located in the fast axis and of which one element at a time is assigned to one emitter of a row of emitters. The arrangement is made furthermore such that the beams [of] the individual emitters which are collimated in the plane of the slow axis with the cylinder lens elements, which are parallel or essentially parallel directly adjoin one another so that a beam cluster with a high filling factor is achieved which then can be focussed using a focussing lens at the focal point.

Optimum focussing of the radiation of all emitters at a common focus however requires optimum fast axis collimation and with it alignment of the individual beams of the emitters of the respective row or respective bar as parallel as possible, such that the emitters could be imaged on a line as straight as possible after this fast axis collimation. But generally this cannot be accomplished in ideal form, due to nonconformities, i.e. deviations of the conformity between the diode laser bars and the fast axis collimator. These deviations can be of different origin, for example due to production tolerances and/or deformation during installation, etc. These nonconformities which are not avoided in the prior art either lead to widening of the focus in the fast axis and thus to degradation of the beam quality at the focus.

The object of the invention is to devise an optical arrangement and a laser diode arrangement with one such optical arrangement which avoids these defects. To achieve this object an optical arrangement is made according to claim 1 and a laser diode arrangement is made according to claim 41.

By dividing at least the part of the correction optics of at least one row of emitter elements, i.e. the part acting as the fast axis collimator, into several segments, the degradation of beam quality at the focus, especially the widening of the focus, which is caused by the nonconformities between the diode laser bars or between the row of emitter elements and the correction optics, can be effectively prevented.

According to another aspect, the invention relates to a special execution of the correction optics such that it is formed by at least one lens element, but preferably by several lens elements which adjoin one another in the direction of the slow axis, which acts or act both as the fast axis collimator and as the slow axis collimator, both effects preferably being accomplished in a single lens body of the respective lens element. Each lens element however can also be built of several lenses following one another in the beam path. If the lens elements each consist of only a single lens body, there is furthermore also the possibility of producing all the correction optics or just segments of these optics in one piece or monolithically.

Developments of the invention are the subject matter of the dependent claims.

The invention is detailed below using the figures on embodiments using the figures.

Figure 1 shows in a simplified representation and in an overhead view a [laser diode arrangement] with several emitters which follow one another on a diode laser bar (chip) in the plane of the drawing in Figure 1 (X-Z plane) in one coordinate direction (X axis), and with an optical arrangement for collimation and focussing of the beams of the individual emitters at a common focus;

Figure 2 shows in a simplified representation and in a side view the laser diode arrangement of Figure 1;

Figure 3 shows a representation similar to Figure 1 in another possible embodiment;

Figure 4 shows in a simplified representation and in an overhead view another possible embodiment of a laser diode arrangement as claimed in the invention with two stacks of diode laser bars which are offset against one another in the direction of the first coordinate axis (X axis), which bars in turn are located in the plane of the drawing of Figure 4, and with an optical arrangement for collimation and focussing of the beams of all emitters at a common focus;

Figure 5 shows in a simplified representation a side view of the laser diode arrangement of Figure 4;

Figure 6 shows a representation similar to Figure 2 to explain the effect of nonconformities between a diode laser bar and a fast axis collimator on the quality of the focus in the laser diode arrangement of Figures 1 and 2;

Figures 7 and 8 show in an overhead view and in a side view another possible embodiment of the laser diode arrangement as claimed in the invention;

Figures 9 - 12 each show in a simplified representation and in an overhead view other possible embodiments of the laser diode arrangement as claimed in the invention;

Figures 13 and 14 show another possible embodiment of the laser diode arrangement as claimed in the invention in representations according to Figures 1 and 2.

For better understanding and simpler orientation, in the figures there are three coordinate axes which run perpendicular to one another labeled X, Y and Z and below they are called the X axis, Y axis and Z axis, and of which the X axis and Z axis jointly define the plane of the drawings (X-Z plane) of Figures 1, 3, 4, 7 and 9-11 and the Y axis and the Z axis together define the planes of the drawings (Y-Z) plane of Figures 2, 5, 6 and 8.

Figures 1 and 2 show a laser diode arrangement which among others consists of a diode laser bar 3 which is located on a cooler 2 (heat sink) and which is produced as a semiconductor chip with a plurality of emitters 5 which emit laser light and which lie with their active layer ideally in a common plane, specifically in the representation chosen for Figures 1 and 2 in the X-Z plane, and following one another in the axial direction which runs in this plane, i.e. in the representation chosen for the figures following one another in the Y axis and spaced apart on the semiconductor chip or bar 3. In the embodiment shown, the laser bar 3 with respect to the extension of the individual

emitters 4 in the direction of the X axis and the distance between these emitters in this axis is made such than the occupancy density is less than 10%, i.e. less than 10% of the entire length which the bar 3 has in the direction of the X axis is occupied by the emitters 4, while the remainder of the length of the laser bar 3 is not radiating.

The individual emitters 4 deliver a laser beam which has divergence both in the fast axis, i.e. in the Y axis, and also in the slow axis, i.e. in the X axis. To eliminate this beam divergence there are optical correction elements, in the beam path following the emitters 4 first a fast axis collimator 5 located directly on the laser bar 3, following this collimator 5 in the beam direction, i.e. in the direction of the Z axis, a slow axis collimator 6 and following this, a focussing means 7 which in the embodiment shown is formed by a focussing lens and with which the beams of all emitters 4 are focussed at a common focal point 8.

As Figure 2 shows, the fast axis collimator 5 produces beams which are parallel in the plane of this fast axis from the beams diverging in the fast axis (Y axis) and which still have divergence in the slow axis, i.e. in the X axis. The fast axis collimator 5 in this embodiment consists of two segments 5' which adjoin one another in the direction of the X axis, with a transition between two emitters on the non-active part of the laser bar 3, and which each correspond in their action to a cylinder lens which extends with its axis in the direction of the X axis. The two elements 5' can be adjusted individually or

independently of one another, and especially by vertical adjustment in the Y axis and by tilting around the Z axis. Also in the other axes can the optical elements 5' be individually adjustable. In the embodiment shown the elements 5' are in fact microcylinder lenses.

The slow axis collimator 6 consists of several optical elements 6' which in their action correspond to one cylinder lens at a time and which with their axis are located in the fast axis, i.e. in the chosen representation in the Y axis. The execution is furthermore such that for each emitter 4 there is one such element 6'. Moreover, the slow axis collimator 6 is located in a plane E perpendicular to the beam path, i.e. perpendicular to the Z axis, on which the edge beams of the beams of adjacent emitters 4 diverging in the slow axis intersect. Moreover the grid size in which the elements 6' on the slow axis collimator 6 are provided in the slow axis (X axis) following one another is equal to the grid size of the emitters 4 on the laser bar 3. The elements 6' directly adjoin one another in the direction of the slow axis.

As Figure 1 shows, the elements 6' convert the beams of the emitters 4 diverging in the slow axis into beams which run parallel in the plane of the slow axis (X-Z plane) so that then the beams which are collimated both in the fast axis and the slow axis can be focussed by the focussing optics 7 at the common focus 8.

The individual elements 6' are preferably combined into a monolithic collimator 6. The relatively low occupation density

of the laser bar 3 makes it possible in the above described manner to provide one element 6' for each emitter 4. Basically it is also possible to provide one common optical element 6' for each of these emitter groups when there are several of them formed on the laser bar 3 which each have at least two emitters 4 located tightly next to another and which then are offset in the direction of the fast axis at a greater distance from one another.

In Figure 1 the power distribution at the focus 8 in the direction of the slow axis (X axis) is labelled 8'. Accordingly, in Figure 2 the power distribution at the focus 8 in the fast axis (Y axis) is labelled 8''. As stated above, faults can occur due to deviations or tolerances between the fast axis collimator 5 and the laser bar 3 and they then lead to widening of the focus 8 in the fast axis, as is shown in Figure 6 by the broken lines of the beam characteristic and by the distribution 8'''. To reduce these faults and achieve the desired diameter of the focus which is the same in both axes, there is individual adjustment of the elements 5' with which then these tolerances in the shaping of the elements 5' and the laser bar 3 can be balanced.

Segmenting the fast axis collimator 5 therefore makes it possible to achieve optical collimation and focussing for both sections of the laser bar 3 which are each assigned to the elements 5'. With respect to the quality of the focus 8 then only the difference in shape between the respective element 5' and the assigned shortened part of the laser bar 3 is relevant, this deviation of shape or tolerance having only a greatly

reduced effect on the quality of the focus 8 due to the shorter relevant length of the laser bar.

In the laser diode arrangement 1 the segmenting is such that all the emitters 4 emit onto the usable surfaces of the fast axis collimator 5, i.e. the connection areas or gaps between the adjoining elements 5' each lying between two emitters 4 which follow one another on the laser bar 3.

Figure 3 shows as a second possibility a laser diode arrangement 1a which differs from the arrangement 1 in that the fast axis collimator 5 is segmented three times, i.e. consists of three elements 5', which can each be individually adjusted so that the effective length of the laser bar 3, i.e. the length assigned to each element 5', is still shorter and thus the influences of tolerances which cannot be balanced by the individual adjustment of the elements 5' on the quality of the focus are still less. Segmenting is also done in the laser diode arrangement 1a such that all emitters 4 radiate onto the usable surfaces of the fast axis collimator, i.e. the connecting areas or gaps between the adjoining elements 5' in turn each lie between two emitters 4 which follow one another in the laser bar 3.

Also different segmenting of the fast axis collimator is of course possible. For example 2x to 5x segmenting is feasible in a laser bar 3 with for example 100 emitters 4.

Figures 4 and 5 show as another embodiment a laser diode arrangement 1b in which the laser bars 3 with their pertinent cooling bodies 2 are located in two stacks 9 and 10. The stacks

9 and 10 are offset against one another in the direction of the X axis. In each stack the laser bars are arranged with the active plane of the emitters 4 in the X-Z plane such that in these figures the fast axis of all emitters 4 is in turn the Y axis and the emitters 4 on each bar 3 follow one another in the direction to the X axis. In each stack 9 the laser diode bars 3 are furthermore offset against one another or spaced apart in the direction of the Y axis by the distance y (Figure 5). As Figures 4 and 5 furthermore show, the stacks 9 and 10 therefore form several stack layers 9' and 10', i.e. in the embodiment shown three layers of stacks at a time, each layer of stacks having a laser bar 3, a fast axis collimator 5 and a slow axis collimator 6 which are arranged and formed in the same way as was described above for the laser diode arrangement 1. In the laser diode arrangement 1b the fast axis collimators 5 are also each segmented twice, i.e. they each consist of two individually adjustable elements 5'.

The parallel beams of the individual emitters collimated in the plane of the fast axis and the slow axis are then focussed via focussing optics 7b which are shared by both stacks 9 and 10 at the common focus 8. In this embodiment as well, with which especially high power can be achieved, the beam quality or the quality of the focus 8 can be greatly improved by the individual adjustment capacity of the individual elements 5'.

The number of elements 5' of the fast axis collimators 5 can of course be chosen differently. Basically it is also possible to choose the number of elements 5' to be different in the

different stack layers 9' and 10', for example, in some stack layers to segment the fast collimators 5 there in two and in some stack layers into three, etc.

Of course it is also possible to provide laser bars 3 in only one stack or in more than two stacks, it also seeming to be especially feasible to adapt the stack height and stack width such that the same extension for the radiation field formed by the emitters 4 results in the slow axis and the fast axis. For example, at a stack height of 30 mm and a stack width of 10 mm then the laser diode arrangement overall would have a total of three stacks which are located next to one another in the direction of the X axis.

In the laser diode arrangement 1b, as described above, for the individual stack layers 9' and 10' there are separate slow axis collimators 6. This makes it possible to adjust these collimators 6 in each stack layer individually with reference to the pertinent laser bars 3 or the emitters 4 there, with which in turn a major improvement of the beam quality or the focus 8 is possible.

In the laser diode arrangement 1b there is one stack layer 9' of the stack 9 located in a common X-Z plane with a stack length 10' of the stack 10.

Figures 7 and 8 show as another possibility a laser diode arrangement 1c in which the planes of the stack layers 9' and 10' and thus the planes of the laser bars 3 (X-Z planes) in the stack 9 are offset by half the distance y relative to the corresponding planes in the stack 10. By means of an optical element 11 which

is located between the slow axis collimators 6 and the focussing optics 7c the beams of the emitters 4 of the stack layers 9' and 10' in the direction of the Z axis are pushed over one another interdigitally such that in the beam path following the optical element 11 in the direction of the fast axis (Y axis) one plane of the beams of the stack layer 10' follows one plane of the beams of the stack layer 9', etc. The beam group produced in this way is then focussed via the common focussing optics 7' at the common focus.

For the sake of simpler representation Figures 7 and 8 show the two stacks 9 and 10 such that each stack has only two stack layers 9' and 10', overall therefore there are four stack layers and thus also four planes in which the laser diode bars 3 are located (the number of stacks multiplied by the number of diode laser bars 3 in each stack).

The optical arrangement 11 consists of several plate-shaped prisms 12 and 13 which are made rectangular in an overhead view, with the same size, and which are oriented with their larger surface sides oriented perpendicular to the fast axis (Y axis) and in this direction adjoin one another stacked on top of one another such that one prism 13 is adjacent to one prism 12 at a time.

The prisms 12 are assigned to the stack 9 and to one diode laser bar 3 of this stack or a stack layer 9' at a time and the prisms 12 are assigned to the stack 10 or one diode laser bar 3 at a time or a stack layer 10' of this stack. Furthermore, the prisms 12 and 13 with their longer peripheral sides which lie in

planes perpendicular to the X-Z plane and which also form the light entry and exit sides of the respective prism, include an angle a (prism 12) and an angle b (prism 13) with the center plane M which runs in the middle between the two stacks 9 and 10 and parallel to the Y-Z plane. Both angles a and b are the same size and are less than 90°, in any case with reversed signs with reference to the center plane M. Furthermore, the angles a and b are chosen such that with consideration of the refractive index when the laser beams enter or exit the prisms 12 and 13 the laser beams are pushed on top of on another in the X axis in the aforementioned manner. Using focussing optics which are not shown then the laser beams of all emitters 4 can again be focussed at a common focus.

Instead of the optical element 11 and the prisms 12 and 13 also other optical elements or means can be used.

While in the laser diode arrangements 1, 1a and 1b essentially an increase of the filling factor in the overall beam supplied for example to the focussing optics 7a and 7b is achieved in the slow axis (X axis), in the laser diode arrangement 1c, by interdigitally pushing the laser beams of the two stacks 9 and 10 on top of one another by means of the optical element 11, the filling factor in the fast axis (Y axis) is increased. If the two stacks 9 and 10 for example have a filling factor of 50% in the fast axis (Y axis), it is for example possible with the laser diode arrangement 1c to transfer the radiation of the adjacent stacks 9 and 10 into a common radiation field with an optical filling factor of almost 100%. The

lengthwise sides of the plate-shaped prisms 12 and 13 form on each prism parallel entry and exit surfaces by which parallel offset or parallel displacement of the laser beams is achieved.

By increasing the filling actor of the beam cluster, at the same power the diameter of the beam cluster is reduced and thus the beam quality which is defined as the product of the beam diameter and the beam divergence is improved, with the power remaining the same. Furthermore, reducing the diameter of the beam cluster also simplifies the following focussing means.

Figures 9 - 11 show as other possible embodiments laser diode arrangements 1d, 1c and 1f. In the laser diode arrangement 1d there are two diode laser bars 3 with one segmented fast axis collimator 5 each and one pertinent slow axis collimator 6 each offset by 90° on a coupling element 14 which is formed by a prism cube. Suitable dielectric filter coatings on the connecting surface 15 which is located at 45° enables combination or coupling of diode laser bars of different wavelength by means of edge filters or by means of different polarization means with polarization filters.

In the laser diode arrangement 1e of Figure 10 three coupling elements 14 are shown for coupling or combination of four diode laser bars 3, each with its own segmented fast axis collimator 5 and its own slow axis collimator 6. Especially in this embodiment with more than two diode laser bars 3 modifications are also conceivable in which not only solely wavelength coupling or polarization coupling, but also combinations thereof, are used.

Figure 11 shows finally as another possible embodiment a laser diode arrangement 1f in which in addition to the coupling element 14 deflection elements 16 and 17 are used which for example are deflection prisms or deflection mirrors and which then allow parallel arrangement of the laser diode bars 3, the pertinent fast axis collimators 5 and the slow axis collimators 6.

It goes without saying that in the laser diode arrangements 1d - 1f stacks with stack layers 9' and 10' which correspond to the stacks 9 and 10 can be used, each stack layer having at least one diode laser bar 3, a pertinent segmented fast axis collimator 5 and a slow axis collimator 6. With the corresponding formation of the coupling elements 14 and/or the deflection elements 16 and 17 and with the correspondingly offset arrangement of the stack layers from stack to stack it is then also possible to push the beams of at least individual diode laser bars 3 of different stacks on top of one another interdigitally to increase the filling factor in the fast axis, as was described above for the laser diode arrangement 1c of Figures 7 and 8 and optionally in addition to wavelength coupling and/or polarization coupling.

Figure 12 shows in one representation similar to Figures 9-11 as another possible embodiment a laser diode arrangement 1d in which the laser diode arrangement 1c of Figures 7 and 8 is provide twice and the beam clusters of the two optical arrangements 11 are combined via an optical coupling element 14 by means of wavelength multiplexing and/or polarization multiplexing into a common beam cluster with an especially high

filling factor. The optical coupling element 14 is then for example in turn one as was described above in conjunction with Figures 9-11.

While in the embodiments of Figures 1-12 it was assumed that the fast axis collimator 5 and the slow axis collimator 6 of the respective correction optics are discrete optical components, Figures 13 and 14 as another possible embodiment show a laser diode arrangement 1h which in turn has at least one diode laser bar 3 with emitters 4 on at least one cooler 2 and in which in the beam path (Z axis) there is correction optics 18 following the diode laser bars. The correction optics 18 is in turn segmented in two in the direction of the slow axis (X axis), i.e. it has in this axial direction two adjoining segments 18', of which at least one can be adjusted individually with reference to the diode laser bars 3 or the emitters there.

Each segment 18' consists of several individual lenses or lens elements 19 which are combined monolithically into the pertinent segment 18' or are connected to the pertinent segment 18' as actual individual lenses. Each individual lens 19 has the function of a fast axis collimator and a slow axis collimator, in the embodiment shown especially such that the beams of the individual emitters 14 in the beam path following the correction optics 18 in the plane of the slow axis are parallel or roughly parallel beams and furthermore the beams of adjacent emitters 4 adjoin one another as tightly as possible, in any case without beam overlapping in the direction of the slow axis (X axis). Each lens element 19 is assigned to one emitter 4 and is made for

example such that it forms on its entry surface one cylinder lens surface which is active in the fast axis and on the exit surface one cylinder lens surface which is active in the slow axis.

Correction of nonconformities between the diode laser bars 3 and the correction optics 18 takes place in the laser diode arrangement 1h by the corresponding adjustment of the segments 18'.

It goes without saying that the correction optics 18 can be made in one piece, i.e. not segmented, especially when compensation of nonconformities between these correction optics and the respective diode laser bars 3 is not necessary. It furthermore goes without saying that the correction optics 18 can of course also be used in laser diode arrangements in which there are two or more as two diode laser bars 3, for example also in one or more stacks, then preferably for each diode laser bar there being its own correction optics 18.

The invention was described above on embodiments. It goes without saying that numerous modifications and versions are possible without departing from the inventive idea underlying the invention. Thus, for example, it is also possible, instead of emitters 4 formed on laser bars 3, to have individual laser diodes with only one emitter each, and which then according to the emitters 4 are provided on a suitable carrier, especially a cooler 2, following one another or spaced apart in the direction of the slow axis (X axis).

Reference number list

1, 1a, 1b, 1c, 1d, 1e, 1f, 1g, 1h	laser diode arrangement
2	cooler
3	diode laser bar
4	emitter
5	fast axis collimator
5'	optical element
6	slow axis collimator
6'	optical element
7, 7b	focussing optics
8, 8b	focus
9, 10	stack
9', 10'	stack layer
11	optical arrangement
12, 13	plate prism
14	optical coupling element, for example prism cube
15	dielectric filter coating
16, 17	deflection element, for example deflection prism
or	deflection mirror
18	correction optics
18'	segment of correction optics
19	lens element
X axis	

Y axis	
Z axis	
Y-Y plane	
X-Z plane	
y = distance	
M	center plane
a, b	angle